WG-331

FINAL
DRAFT

AC/AMJ 20-TBD

AIRCRAFT LIGHTNING ZONING

Draft of 19 Nov. 1998
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1.0 PURPOSE

The purpose of this AC/AMJ is to provide information to determine the lightning attachment zones which is referred to as Lightning Zoning. This AC/AMJ is used in conjunction with two other documents, *AC/AMJ 20-TBD Aircraft Lightning Environment and Relative Test Waveforms* and ED-TBD/ARP-TBD *Lightning Testing Standard(Ref. 4.1 and 4.2)*. The relationship between the three documents is shown in Figure 1-1. These three documents are used to define the aircraft lightning threat and tests required to support the aircraft lightning protection certification.

Lightning zoning is a functional step in demonstrating that the aircraft is adequately protected from both direct and indirect effects of lightning. The purpose of lightning zoning is to determine the surfaces of the aircraft which are likely to experience lightning channel attachment and the structures which may experience lightning current conduction between pairs of entry/exit points.

Zoning should be used with the aircraft hazard assessment to determine the appropriate protection for a given aircraft part or location. To determine the appropriate protection for parts and structure in a particular lightning zone, the criticality of the systems or structure in the zone should be considered.

2.0 SCOPE

This AC/AMJ defines lightning strike zones and provides guidelines for locating them on particular aircraft, together with examples. The zone definitions and location guidelines described herein are applicable to Parts 23, 25, 27, and 29 aircraft. The zone location guidelines and examples are representative of in-flight lightning exposures.

3.0 RELATED FAR AND JAR INFORMATION

3.1 Federal Aviation Regulations (FAR)

Federal Aviation Regulations 14 CFR Parts 23.867, 23.954, 23.1209(e), 23.1316, 25.581, 25.954, 25.1316, 27.610, 27.954, 27.1309(d), 27.1316, 29.610, 29.954, 29.1309(h), 29.1316 and 33.28(d).

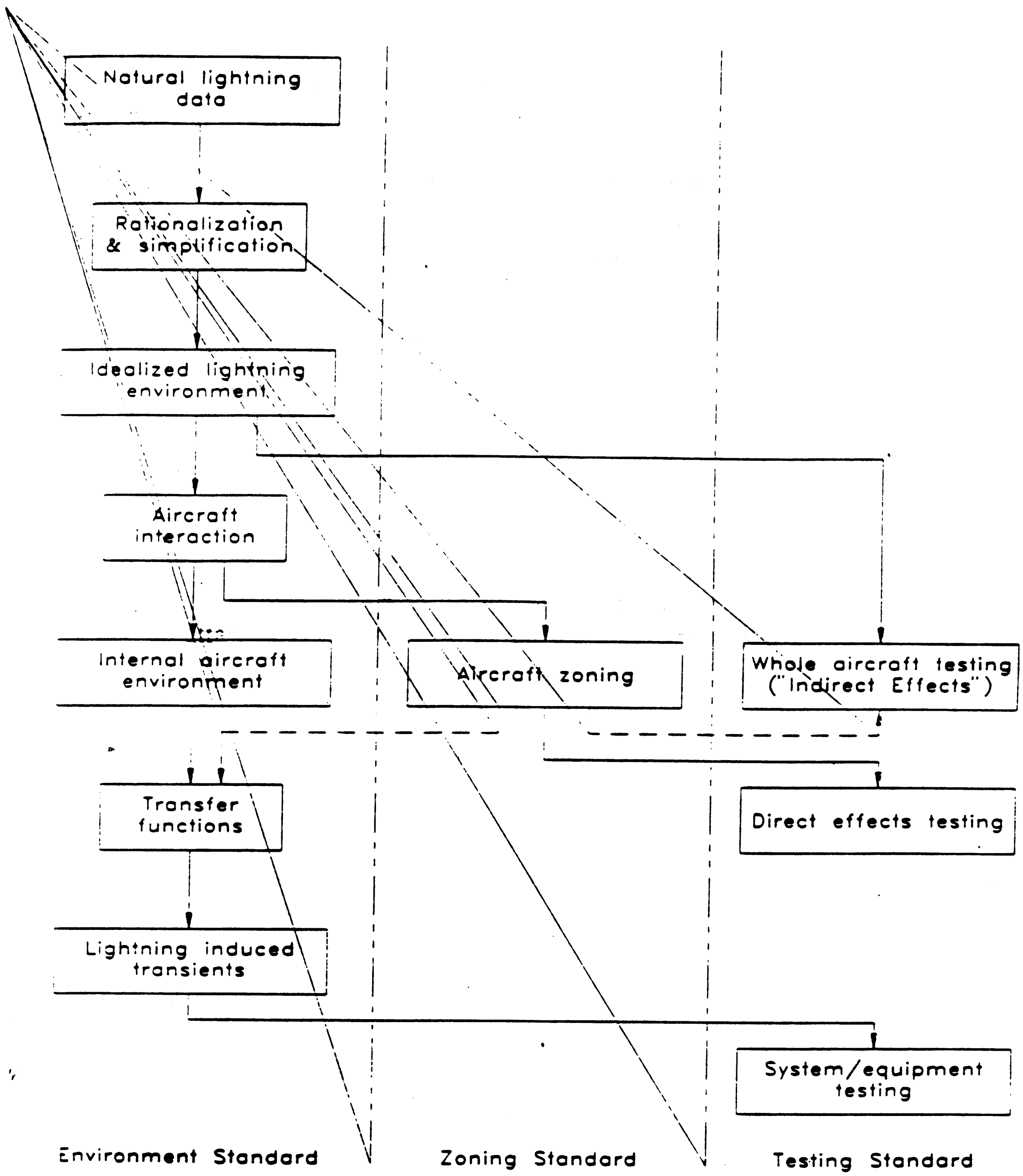


Figure 1-1 - Relationship between aircraft environment, zoning and testing standards

Note: Solid lines represent the actual AC/AMJ and Standard's materials and processes addressed in the documents. The dotted lines represent the supporting materials and processes.

3.2 FAA Advisory Circulars

The following Advisory Circulars (AC) may provide additional information.

3.2.1 AC 23.1309-1B, System and Equipment Installations in Part 23 Airplanes, dated July 28, 1995.

3.2.2 AC 25.1309-1A, System Design and Analysis, dated June 21, 1988.

3.2.3 AC 27-1A, Certification of Normal Category Rotorcraft, dated September 30, 1997.

3.2.4 AC 29-2B, Certification of Transport Category Rotorcraft, dated July 30, 1997.

3.2.5 AC 21-16D, Radio Technical Commission for Aeronautics Document DO-160D, dated March, 1998.

3.3 Joint Airworthiness Requirements (JAR)

Joint Airworthiness Requirements Parts 23.867, 23.954, 23.1209(e), 23.1316, 25.581, 25X899, 25.954, 25.1316, 27.610, 27.954, 27.1309(d), 27.1316, 29.610, 29.954, 29.1309(h), 29.1316 and 33.28(d). JAR E.50.

3.4 JAA Advisory and Interpretive Material

3.4.1 ACJ 25.581, Lightning Protection (Acceptable Means of Compliance and Interpretative Material).

3.4.2 ACJ 25X899, Electrical Bonding and Protection Against Lightning and Static Electricity (Interpretive Material and Acceptable Means of Compliance).

3.4.3 ACJ 29.610, Lightning and Static Electricity Protection (Interpretive Material and Acceptable Means of Compliance).

3.4.4 AMJ 20X-1, Certification of Aircraft Propulsion Systems Equipped with Electronic Controls.

4.0 REFERENCE DOCUMENTS

4.1 AC/AMJ 20-TBD Aircraft Lightning Environment and Relative Test Waveforms

4.2 EUROCAE WG 31 ED-TBD/SAE AE4L ARP-TBD document (in preparation) "Aircraft Lightning Testing Standard"

4.3 EUROCAE ED-14D/RTCA DO-160D
"Environmental Conditions and Test Procedures for Airborne Equipment"
Section 22: "Lightning Induced Transient Susceptibility"

4.4 EUROCAE ED-14D/RTCA DO-160D
"Environmental Conditions and Test Procedures for Airborne Equipment"
Section 23: "Lightning Direct Effects"

4.5 AC/AMJ AC 20-136A
"Protection of Aircraft Electrical/Electronic Systems against the Indirect Effects of Lightning" [EUROCAE ED-81/SAE AE4L-87-3 Revision C]

4.6 AC/AMJ 20-53B
Protection of Airplane Fuel Systems Against Fuel Vapor Ignition Due to Lightning"

4.7 User's Guide for SAE AE4L Committee Report AE4L-87-3 Revision C
EUROCAE WG 31/SAE AE4L document (in preparation).

5.0 BACKGROUND

Lightning zoning is a fundamental step in determining appropriate lightning protection for aircraft. Guidance on lightning zoning was previously incorporated into AC/AMJs pertaining to fuel and electrical/electronics systems protection. However, because of the general application of lightning zoning to protection of all parts of an aircraft, the aircraft lightning zoning information has been deleted from those AC/AMJs, updated, and presented in this AC/AMJ.

This AC/AMJ includes clarification of the original zone definitions, introduction of a transition zone between Zones 1A and 2A, consideration of the effects of swept lightning leaders, and clarification of the influence of small protrusions on zoning.

6.0 DEFINITIONS/ABBREVIATIONS/ACRONYMS

6.1 Definitions

<u>Attachment Point</u>	A point of contact of the lightning flash with the aircraft.
<u>Breakdown</u>	The production of a conductive ionized channel in a dielectric medium resulting in the collapse of a high electric field.
<u>Dwell Point</u>	A lightning attachment point.

Dwell Time	The time that the lightning channel remains attached to a single spot on the aircraft.
External Environment	Characterization of the natural lightning environment for design and certification purposes.
First Return Stroke	The high current surge that occurs when the leader completes the connection between the two charge centers. The current surge has a high peak current, high rate of change of current with respect to time (di/dt) and a high action integral.
Flashover	This term is used when the arc produced by a gap breakdown passes over or close to a dielectric surface without puncture.
Leader	The low luminosity, low current precursor of a lightning return stroke, accompanied by an intense electric field.
Lightning Channel	The ionized path through the air along which the lightning current pulse passes.
Lightning Flash	The total lightning event. It may occur within a cloud, between clouds or between a cloud and ground. It can consist of one or more return strokes, plus intermediate or continuing currents.
Lightning Strike	Any attachment of the lightning flash to the aircraft.
Lightning Strike Zones	Aircraft surface areas and structures classified according to the possibility of lightning attachment, dwell time and current conduction.
Reattachment	The establishment of new attachment points on the surface of an aircraft due to the sweeping of the flash across the surface of the aircraft by the motion of the aircraft.
Restrike	A subsequent high current surge attachment, which has a lower peak current, a lower action integral, but a higher di/dt than the first return stroke. This normally follows the same path as the first return stroke, but may reattach to a new location further aft on the aircraft.
Stepped Leader	See leader.

Swept Leader	A lightning leader that has moved its position relative to an aircraft, subsequent to initial leader attachment, and prior to the first return stroke arrival, by virtue of aircraft movement during leader propagation.
Swept Channel	The lightning channel relative to the aircraft, which results in a series of successive attachments due to sweeping of the flash across the aircraft by the motion of the aircraft.
Zoning	The process (or the end result of the process) of determining the location on an aircraft to which the components of the external environment are applied.

6.2 Abbreviations

A	amperes
AC	Advisory Circular
AMJ	Advisory Material Joint
C	charge transfer (coulombs or ampere - seconds)
d	distance (meters)
h	altitude above ground (meters)
kA	kiloamperes
kV	kilovolts
kV/m	kilovolts per meter
m/s	meters per second
ms	milliseconds
s	seconds
t	time
v	velocity (meters/second)

6.3 Acronyms

AGL	Above ground level
CAD	Computer aided design
EFM	Electric field modeling
HC	High current
HV	High voltage
TAS	True Air Speed
3D	Three-dimensional

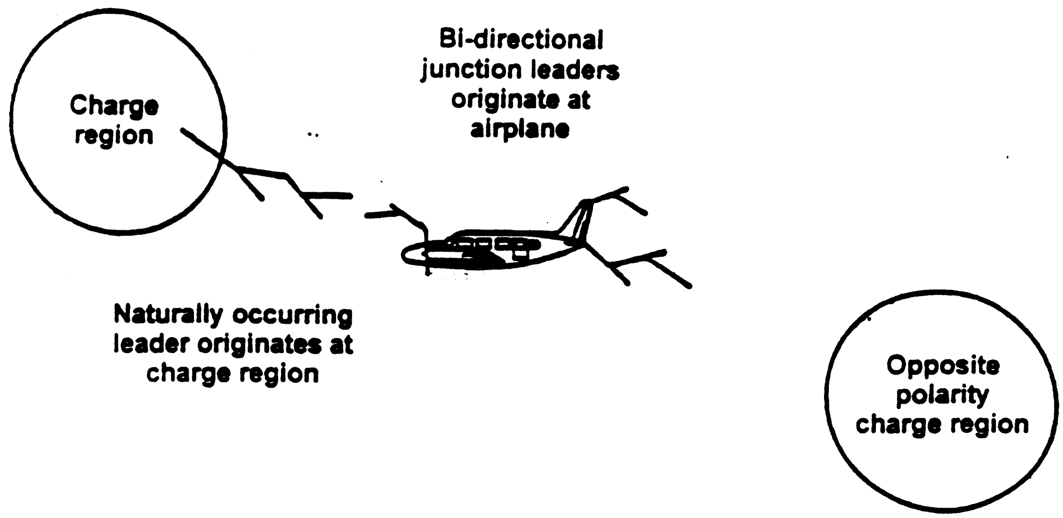
7.0 AIRCRAFT LIGHTNING INTERACTION

7.1 Initial Lightning Attachment

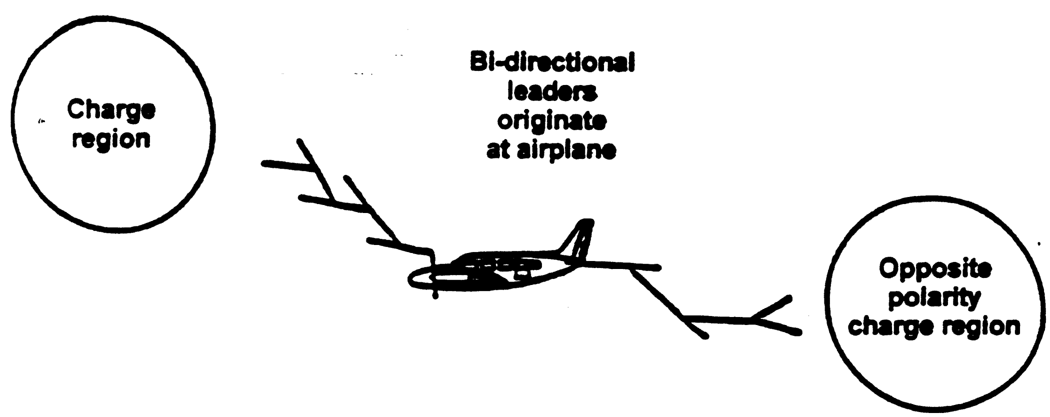
Aircraft in flight are exposed to both naturally occurring and aircraft initiated ("triggered") lightning strikes. A naturally occurring strike begins when a lightning leader which originates at a cloud charge center happens to approach an aircraft.. When this happens, the electric field associated with charge in the leader intensifies about the aircraft extremities, and discharges, called junction leaders, emanate from major extremities and, propelled by the electric field, propagate in the general direction of the lightning leader. One, and sometimes more of these junction leaders may connect with one or more branches of the lightning leader. The aircraft surfaces where these junction leaders originated from thus become the initial lightning attachment points. Often these are referred to as initial attachment (or "entry") points. At the same time additional junction leaders, originating at other extremities, are propagating away from the airplane, in the general direction of a region of opposite polarity charge. This may be the earth, or it may be a cloud charge region of opposite polarity. The location(s) from which these leader(s) leave the aircraft constitute other initial lightning attachment locations, often called exit points.

An aircraft-initiated strike may result when the aircraft is in an electric field associated with charged cloud regions and the field intensity about the aircraft's extremities is sufficient to initiate and propel bi-directional leaders, from these extremities. These leaders propagate between regions of opposite polarity charge, and conduct lightning currents through the airplane, as occurs with naturally occurring lightning. The places from which the bi-directional leaders originate are also called initial entry and exit points. There is no generic difference in the characteristics of entry and exit locations. The terms are used only for convenience in describing the overall lightning process, and are perhaps more relevant to a naturally occurring lightning strike, wherein the entry location is associated with the initially approaching leader, and the exit location means the place from which the leader continues its journey to an ultimate destination. Examples of the two lightning strike mechanisms described above are shown in Figure 7-1.

The same aircraft locations may be initial entry/ exit points for either type of lightning strike. Lightning entry/exit locations exist typically at aircraft extremities such as nose, wing and
empennage tips, tail cones, propellers and rotor blades, and some engine nacelles.



a. Naturally occurring strike



b. Aircraft initiated strike

Figure 7-1 - Lightning Strike Mechanisms

7.2 Swept Channel Process

The completed lightning channel is somewhat stationary in air. When an aircraft has been struck, currents in the channel flow through the aircraft. However, due to the speed of the aircraft and the length of time that the lightning channel exists, the aircraft can move a significant distance relative to the lightning channel. When a forward extremity, such as a nose or wing mounted engine nacelle is an initial leader attachment point, the movement of the aircraft through the lightning channel usually causes the channel to sweep back over the surface as illustrated in Figure 7-2, allowing the channel to reattach to airplane surfaces aft of the initial attachment point. This is known as the swept-channel process. The characteristics of the surface can cause the lightning channel to reattach to and dwell at various surface locations for different periods of time, resulting in a series of successive lightning attachment points along the sweeping path. These subsequent attachment points have been referred to as dwell points.

The amount of damage produced at any dwell point on the aircraft by a swept channel depends upon the type of the aircraft skin material and finish, the dwell time at that point, and the lightning currents which flow during the attachment. Stroke currents as well as intermediate currents and small portions of continuing currents may occur at any attachment point. Subsequent strokes flowing in the channel sometimes cause it to reattach to new dwell points.

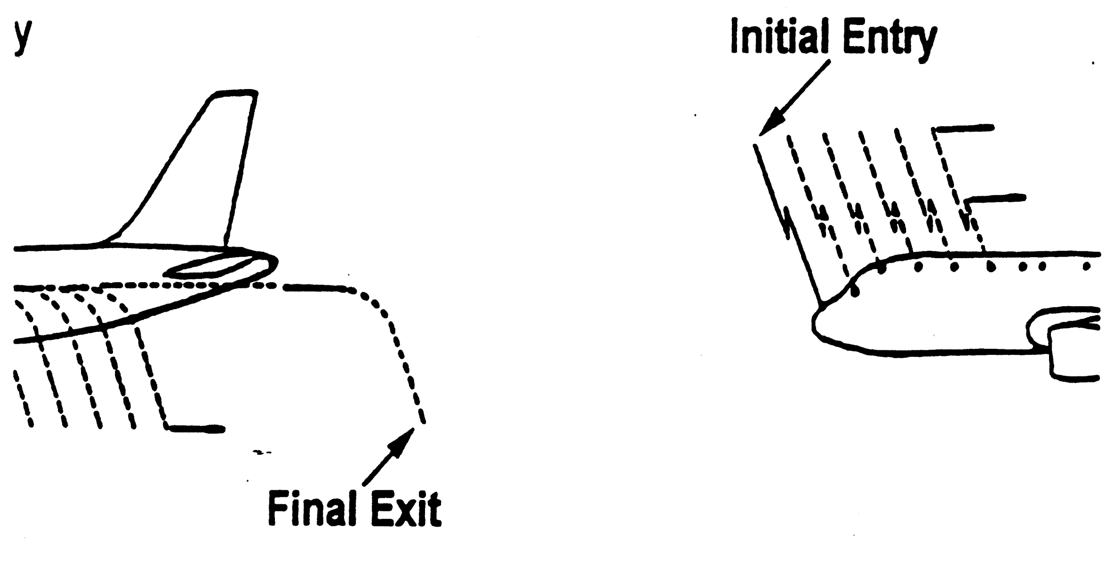


Figure 7-2 - Typical Path of Swept-Channel Attachment Points

When the lightning channel has been swept back to a trailing edge, it may remain attached at such an edge for the remaining duration of the lightning flash. An initial leader attachment location at an aircraft trailing edge, of course, could not be subjected to any swept-channel action; and therefore, all components of the lightning flash currents would enter or exit from this location.

The significance of the swept-channel phenomenon is that surfaces of the vehicle that would not be susceptible to initial lightning attachment may also be involved in the lightning strike process as the lightning channel is swept backwards, although the channel may not remain attached at any single point for very long. On the other hand, strikes that reach trailing edges should be expected to remain attached and hang on there for the balance of their natural duration.

7.3 Conduction

During the time that the lightning channel is attached to any of the aircraft initial attachment or swept channel dwell points, currents will be flowing in the aircraft. The points of entry and exit of this current from the aircraft will change as the airplane flies through the lightning channel, as described in Section 7.2.

The lightning current will distribute among all electrically conductive skins and structural elements between entry and exit locations. Some lightning current may also flow in non-structural components, such as push rods, hydraulic lines, plumbing, and electrical cables.

The magnitudes of currents that flow in various structural elements depend upon a variety of factors including geometry, material properties, and the characteristics of the lightning currents.

8.0 ZONE DEFINITIONS

The surface of an aircraft can be divided into a set of regions called lightning strike zones. These zones represent the areas likely to experience the various types of lightning currents and consequently, the various components of the lightning environment defined in Ref. 4-1. There are three major divisions representing:

1. Regions likely to experience initial lightning attachment and first return strokes.

2. Regions which are unlikely to experience first return strokes but which are likely to experience subsequent return strokes. This will happen where the aircraft is in motion relative to a lightning channel causing sweeping of the channel backwards from a forward initial attachment point.

3. Regions which are unlikely to experience any arc attachment but which will have to conduct lightning current between attachment points.

Regions 1 and 2 are subdivided into specific lightning attachment zones as follows:

Zones 1A and 2A, where long hang-on of a lightning channel is unlikely because the motion of the aircraft with respect to the channel causes the arc root to move across the surface of the aircraft in the opposite direction from the direction of motion.

Zones 1B and 2B, where the lightning channel attachment point is unlikely to move during the remainder of the flash because the location is a trailing edge or a large promontory from which the relative motion of the aircraft and channel cannot sweep the attachment point further.

Finally, an additional zone, Zone 1C, is defined, in which by virtue of the change in current parameters along a lightning channel and the time taken for sweeping of the attachment point across the surface of the aircraft, the threat to the aircraft is reduced.

Specific zone definitions are as follows:

Zone 1A - First return stroke zone

All the areas of the aircraft surfaces where a first return stroke is likely during lightning channel attachment with a low expectation of flash hang on.

Zone 1B - First return stroke zone with long hang on

All the areas of the aircraft surfaces where a first return stroke is likely during lightning channel attachment with a high expectation of flash hang on.

Zone 1C - Transition zone for first return stroke

All the areas of the aircraft surfaces where a first return stroke of reduced amplitude is likely during lightning channel attachment with a low expectation of flash hang on.

Zone 2A - Swept stroke zone

All the areas of the aircraft surfaces where subsequent return stroke is likely to be swept with a low expectation of flash hang on.

Zone 2B - Swept stroke zone with long hang on

All the areas of the aircraft surfaces into which a lightning channel carrying a subsequent return stroke is likely to be swept with a high expectation of flash hang on.

Zone 3

Those surfaces not in Zones 1A, 1B, 1C, 2A or 2B, where any attachment of the lightning channel is unlikely, and those portions of the aircraft that lie beneath or between the other zones and/or conduct substantial amount of electrical current between direct or swept stroke attachment points.

The location of these zones on any particular aircraft shall be agreed between the applicant and the appropriate certification authority.

9.0 WAVEFORM APPLICABILITY

The applicability of the lightning environment waveforms to each of the zones is described in AC/AMJ 20-TBD.

10.0 ZONE LOCATION PROCESS

The locations of the lightning strike zones on any aircraft are dependent on the geometry of the aircraft and operational factors. If a new/modified aircraft is similar to an existing aircraft whose zoning has been validated by service history, the new/modified aircraft can be zoned in the same manner as the existing aircraft, as described in Section 10.8. For aircraft that are of new or novel design (or for areas of an aircraft that incorporate new or novel design), use the eight steps below to determine the lightning zones. This process is illustrated in Figure 10-1. Note that for a new/modified aircraft, the unmodified areas can be zoned by similarity and the new/modified areas can be zoned by the following method.

10.1 Determination of Initial Lightning Leader Attachment Locations

The first step in locating the lightning strike zones is to determine the locations where lightning leaders may initially attach to an aircraft. Various methods are available to accomplish this task. They include such methods as similarity, testing and analysis (i.e., EFM, Rolling Sphere). Further descriptions of those methods are found in Section 11.0. Whichever method(s) are used, the results should be applied in the light of previous in-flight lightning strike experience of airframes with similar geometry (if available) or known aspects of lightning attachment phenomenology. These initial attachment locations typically include extremities such as the nose, wing and empennage tips, propellers and rotor blade tips, some engine nacelles, cockpit window frames, and other significant projections.

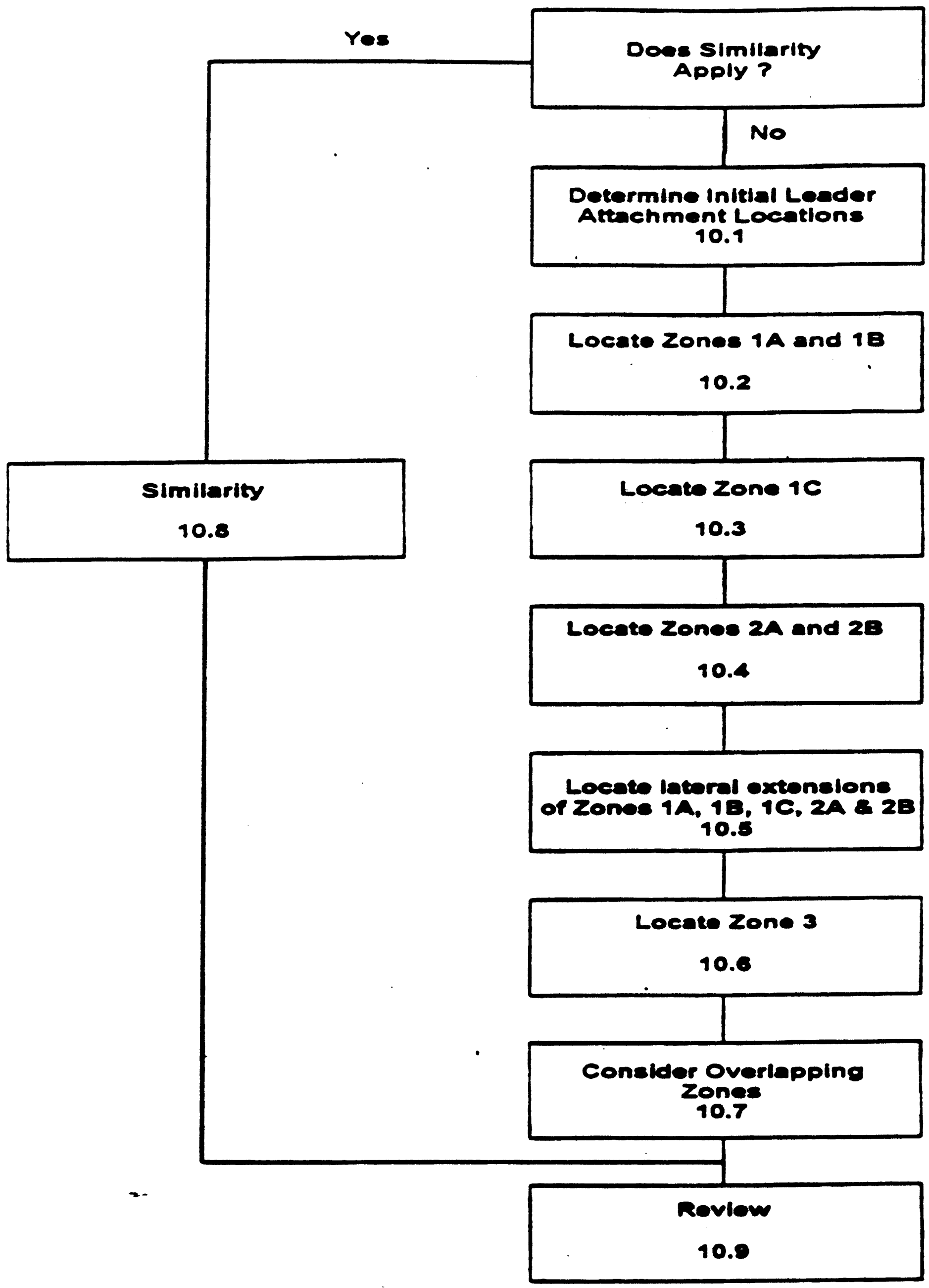


Figure 10-1 - Zone Location Process

Lightning strikes to typical initial entry/exit locations on an airplane do not always occur to the same spot, but may, due to statistical variations in air breakdown phenomena, occur to a variety of locations on the same overall extremity, especially if the extremity does not have a significant protrusion, or a sharp edge where an electric field would be especially enhanced. Thus large surface areas comprising the rounded nose of an airplane are susceptible to initial leader attachment, whereas only the forward-most tip of a narrow, sharp-nosed airplane would be likely to experience initial leader attachment.

Initial leader attachment locations found in the first step that are on trailing edges are likely to experience all or a significant part of the lightning flash as the arc cannot sweep from these surfaces to anything further rearward in the airflow. Thus, these initial attachment locations will also experience long hang-on of the lightning channel and are therefore defined as being within Zone 1B.

10.2 Location of Zones 1A and 1B

The second step in locating the lightning strike zones is to determine the additional locations for possible first return stroke arrival. These locations will include Zones 1A, 1B, and 1C. In most cases the aircraft will be moving forward when struck and the leader will have swept aft from its original forward attachment point by the time the leader reaches the earth (or other charge center) and initiates the first return stroke. A distance, flown by the aircraft during this period determines the aft extension of Zone 1A surfaces from the initial leader attachment points and is dependent upon aircraft speed, aircraft altitude above the earth (for a cloud-to-ground strike), and leader velocity. The starting point for the Zone 1A extension should be the aft extremity of the initial attachment region.

Equation 10-1 shows the relationship of the maximum leader sweep distance (d) as a function of aircraft altitude (h), leader velocity (V_l), and true aircraft speed (*TAS*).

$$d = h \, TAS / V_l \qquad (10\text{-}1)$$

Note: It is important to note that all values used in this formula must be in metric units.

The application is shown in Figure 10-2.

Experience indicates that most severe strike encounters, which include current Component A, involve cloud-to-ground flashes that strike the aircraft at altitudes of 1500 m (5,000 ft) or less, so Zone 1A extensions can be based on this altitude. The leader velocity should be taken as 1.5×10^5 m/s.

Typical aircraft speeds below 1500 m (5,000 ft) are less than 130 m/s (250 knots.) Therefore a Zone 1A extension d_1 of 1.3 m should be used. For aircraft with lower operating speeds the extension distance d_1 may be reduced proportionally to a minimum of 0.5 m.

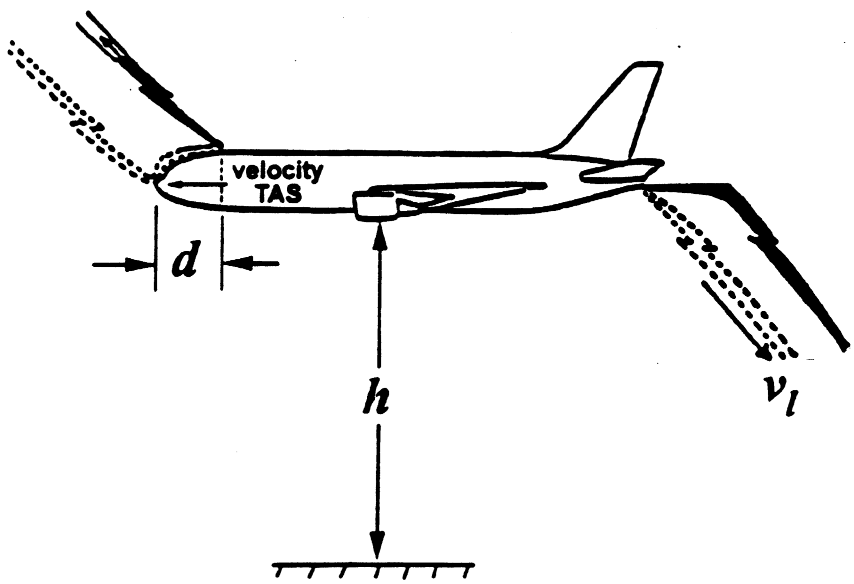


Figure 10-2 - Leader Sweep, Aircraft Altitude and Aircraft Leader Velocities

Initial leader attachment locations where the lightning channel must hang on for the duration of its lifetime are in Zone 1B. Because Zone 1B locations cannot involve sweeping as they are already as far back on aircraft surfaces as it is possible for them to be, no additional analysis is required for them.

10.3 Location of Zone 1C

Zone 1C is applicable to surfaces aft of Zone 1A which can be reached by swept leaders at flight altitudes between 1500 m (5,000 ft) and 3000 m (10,000 ft). In this range a return stroke of lower amplitude than Component A, called current Component A_h, is applicable. The rearward limit of this channel sweep distance is calculated from the formula shown in Equation 10-1, using an altitude (h) of 3000 m (10,000 ft). This gives a distance d_2 from the rearward edge of initial attachment regions.

Typical aircraft speeds below 3000 m (10,000 ft) are less than 130 m/s (250 knots.) Therefore a total leader sweep distance d_2 of 2.6 m should be used. The aircraft surfaces lying between distances d_1 and d_2 limits are Zone 1C. For aircraft with lower operating speeds or lower operating altitudes, the total leader sweep distance d_2 may be reduced accordingly. Therefore, in some circumstances Zone 1C may not be present.

An example of the Zone 1A and Zone 1C locations is shown on Figure 10-3.

10.4 Location of Zones 2A and 2B

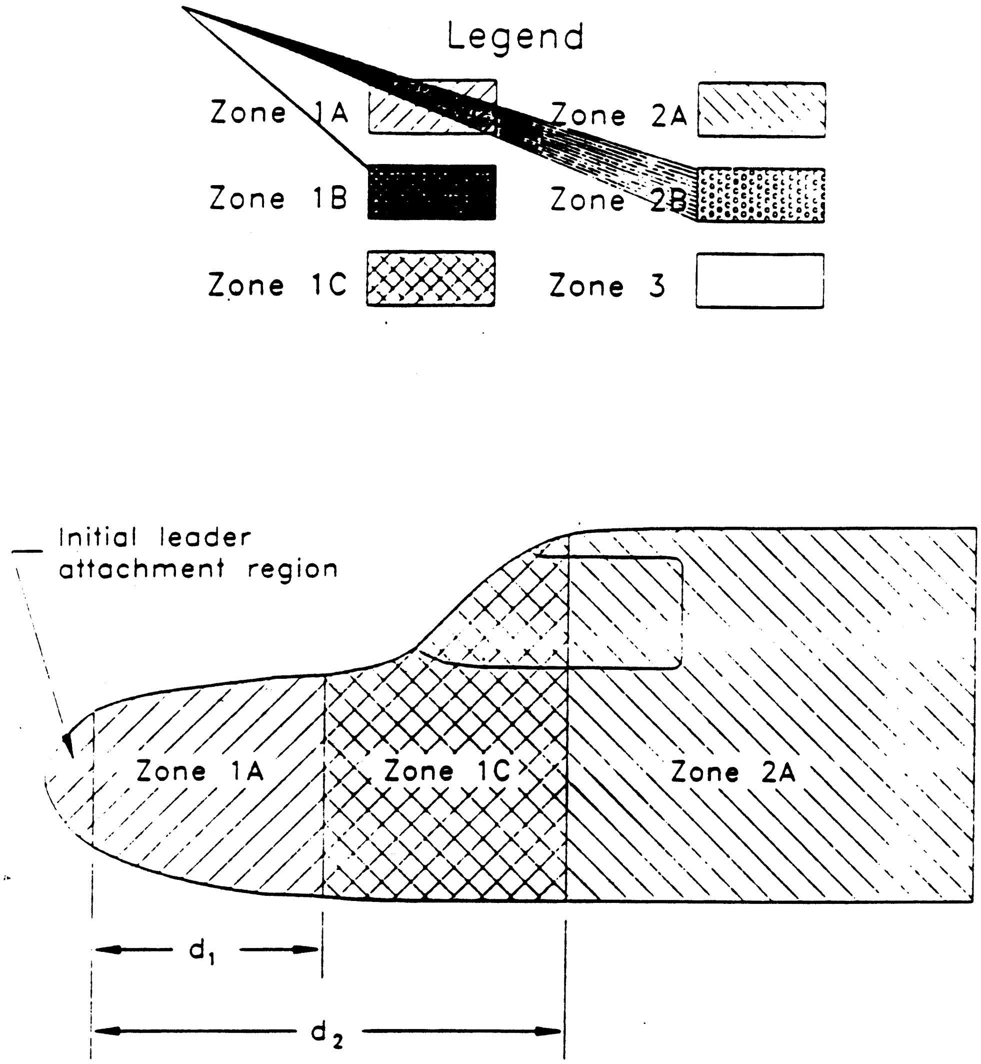
Since all aircraft can travel more than their entire length in the one or two second duration of a lightning flash, the remainder of the surfaces aft of Zone 1C should be considered within Zone 2A. Trailing edge surfaces aft of Zone 2A should be considered in Zone 2B unless they have already been located within Zone 1B.

10.5 Location of Lateral Extensions of Zones 1A, 1B, 1C, 2A and 2B

In the determination of the Zone 1A and 1B surface area of wing and empennage tips that are curved or swept or have winglets, it is advisable to determine the horizontal tangent point of the tip curvature and extend the Zone 1A and 1B inboard 0.5 m.

In addition, to account for the lower probability of a direct attachment of a reduced amplitude strike and/or small lateral movements of the lightning channel inboard of Zones 1A and 1B at wing and empennage tips, the surfaces 0.5 m inboard of Zones 1A and 1B should be considered as within Zones 2A and 2B.

Examples of this are provided in Figure 10-4.

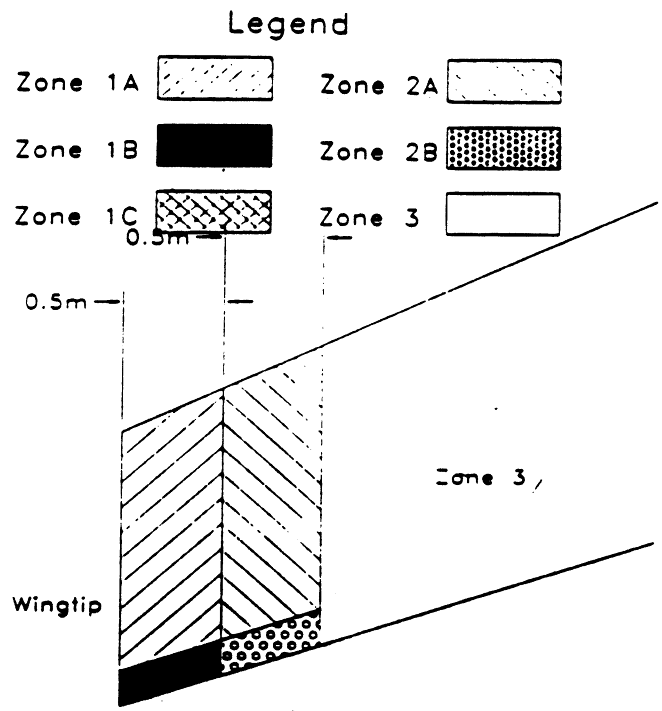


$$d_1 \quad h_1 \frac{TAS}{v}$$

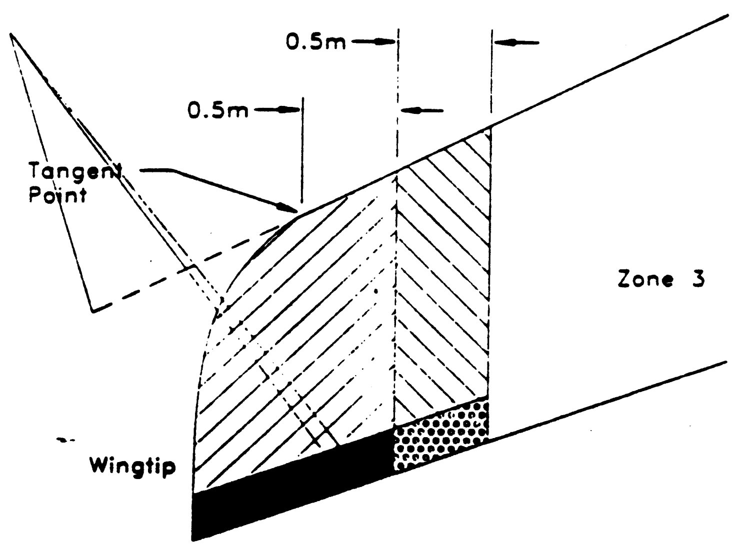
$$d_2 \quad h_2 \frac{TAS}{v}$$

where: $v\square = 1.5 \times 10^5$ m/s
$h_1 = 1524$ m (5,000 ft.)
$h_2 = 3048$ m (10,000 ft.)
TAS = 134 m/s (250 KTS)

Figure 10-3 - Examples of Zones 1A and 1C Locations



a) Straight Wingtip



b) Curved Wingtip

Figure 10-4 - Examples of Wing and Empennage Tip Zones

Surfaces 0.5 m (18 in.) to either side (i.e. outboard or inboard) of Zones 1A, 1C, 1B, 2A, and 2B along the wing roots, wing-mounted engines, and vertical and horizontal stabilizer roots determined by Steps 10.1 through 10.4 should also be considered within these same zones to account for small lateral movements of the lightning channel.

10.6 Location of Zone 3

Those surfaces not in Zones 1A, 1C, 1B, 2A and 2B and where any attachment of the lightning channel is unlikely are considered to be in Zone 3. Zone 3 includes those portions of the aircraft that lie beneath or between the other zones and which conduct lightning current between areas of direct or swept-channel attachment.

10.7 Overlapping Zones

Surfaces within Zones 1A and 1C are also in Zone 2A, as in some cases the first return stroke may occur near the initial leader attachment point, as at a nose or engine inlet cowl, with subsequent strokes occurring within the rest of the Zone 1A areas. Zone 3 also underlies all other zones. Protection designs should be based on the worst case zones.

10.8 Zoning by Similarity

Similarity with a previously certified aircraft may be used as the basis for zoning a new or derivative aircraft. In making a similarity assessment, the following should be considered:

1. No significant differences exist between the geometry of the previously certified aircraft and that of the new or derivative aircraft, such as differences in:

    - Radius of curvature and size of structure, or sweep of the wing
    - Configuration, such as number of engines, empennage type, or low/high wing
    - Large protrusions such as a large blade antenna, aerodynamic fence, or fuel dump

2. Service lightning strike experience indicates that no changes in the zone locations are warranted.

3. No significant change in the electrical conductivity of the aircraft surfaces such as replacement of an aluminum surface with a non-conductive fiberglass surface. See also Section 12.2.

4. No significant changes in flight characteristics, such as aircraft speed and altitude envelope.

If only certain parts of an aircraft are similar to the previously certified aircraft those similar parts may be zoned by similarity. The non-similar parts should be zoned in accordance with applicable steps in Section 10.
For example, a transport aircraft whose nose, cockpit, and wing geometries are similar to those of a previously certified aircraft but whose fuselage is to be longer than the previously certified aircraft could be zoned completely based on the previously certified aircraft.

An aircraft whose wings are to be swept as compared with a previously certified straight wing aircraft but whose forward fuselage geometry is to be similar could utilize the previously certified aircraft zones to zone the nose and fuselage areas, but not the wing. Zoning of the wing surfaces should be accomplished in accordance with the process described in Section 10.

Also, the rotor blades and upper surfaces of a helicopter whose fuselage and rotor blade geometries are similar to a previously certified helicopter, but whose undercarriage is different (i.e., retractable instead of fixed landing gear) could be zoned based on the previously certified helicopter, but the lower surfaces would have to be zoned in accordance with the process of Section 10, or the zones of a previously certified helicopter whose lower fuselage and undercarriage geometrics are similar to those of the helicopter to be zoned.

10.9 Review

Once the lightning strike zones have been established, they should be documented on a drawing of the aircraft, with boundaries identified by appropriate station numbers or other notations. The zone locations should be reviewed with the certifying authority and concurrence of the certifying authority should be obtained.

10.10 Examples of Zone Locations

Lightning strike zones located in accordance with the above guidelines are illustrated in Figures 10-5 through 10-11 for transport and general aviation aircraft and rotorcraft.

Rotorcraft may be airborne with motion in any direction relative to a lightning channel, or have no motion at all. Thus, with the exception of rotor blades, any potential initial attachment points may experience all components of the standard lightning environment, and, therefore, need to be treated as being within Zone 1B. Swept channel attachments may occur in any direction from these Zone 1B regions, therefore, all undersurfaces not already designated Zone 1B should be considered as within Zone 1A. Rotor blades may sustain initial leader attachments to their tips and thus surfaces 0.5 m inboard of blade tip should be considered as within Zone 1A. Blade surfaces inboard of Zone 1A should be considered in Zone 2A. Much of the upper fuselage surfaces are normally protected from lightning attachment by the rotor blades and may be treated as within Zone 3. An example of these lightning strike zones is shown in Figure 10-11.

Propellers are usually in Zone 1A as illustrated in Figures 10-9 and 10-10, although other zones may be applicable based on the propeller locations with respect to other parts of the airframe. The zone location process described in Sections 10.1 through 10.7 should be followed.

The dwell times of intermediate or continuing currents (Components B and C*) on propeller and rotor blade surfaces may differ from those described in Ref. 4.1 for conventional aircraft surfaces and should be determined by analysis.

Nacelle and other aircraft surfaces within a 45□ projection aft of the propeller blade tips may be considered as within Zone 3 as illustrated in Figures 10-9 and 10-10 unless such surfaces are designated as within an attachment zone for other reasons, e.g., the exposed specimen on a pusher propeller, which is normally in Zone 1B.

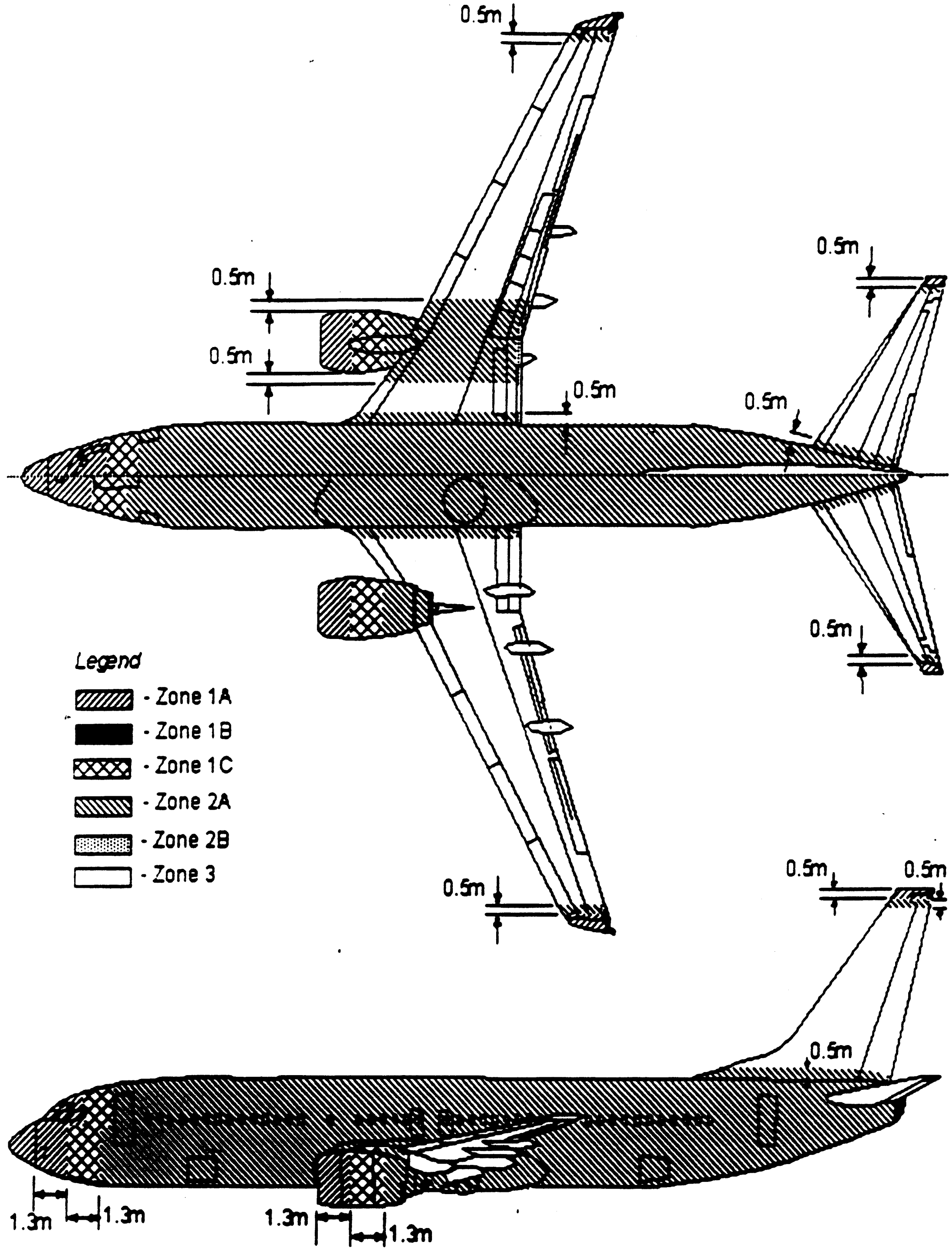


Figure 10-5 - Example of Lightning Strike Zone Details for Transport Aircraft

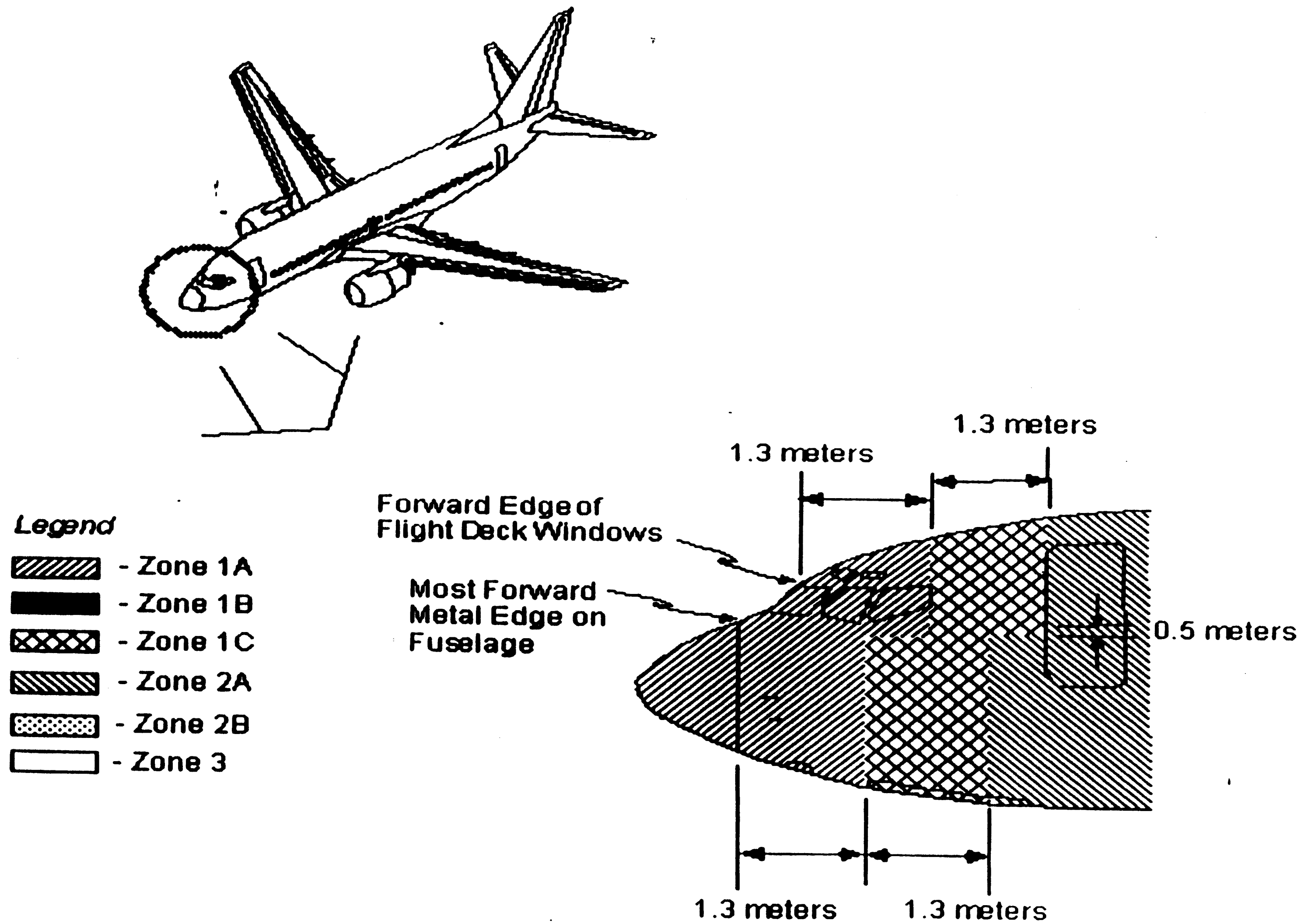


Figure 10-6 - Example of Lightning Strike Zone Details for Transport Aircraft Nose and Flight Deck

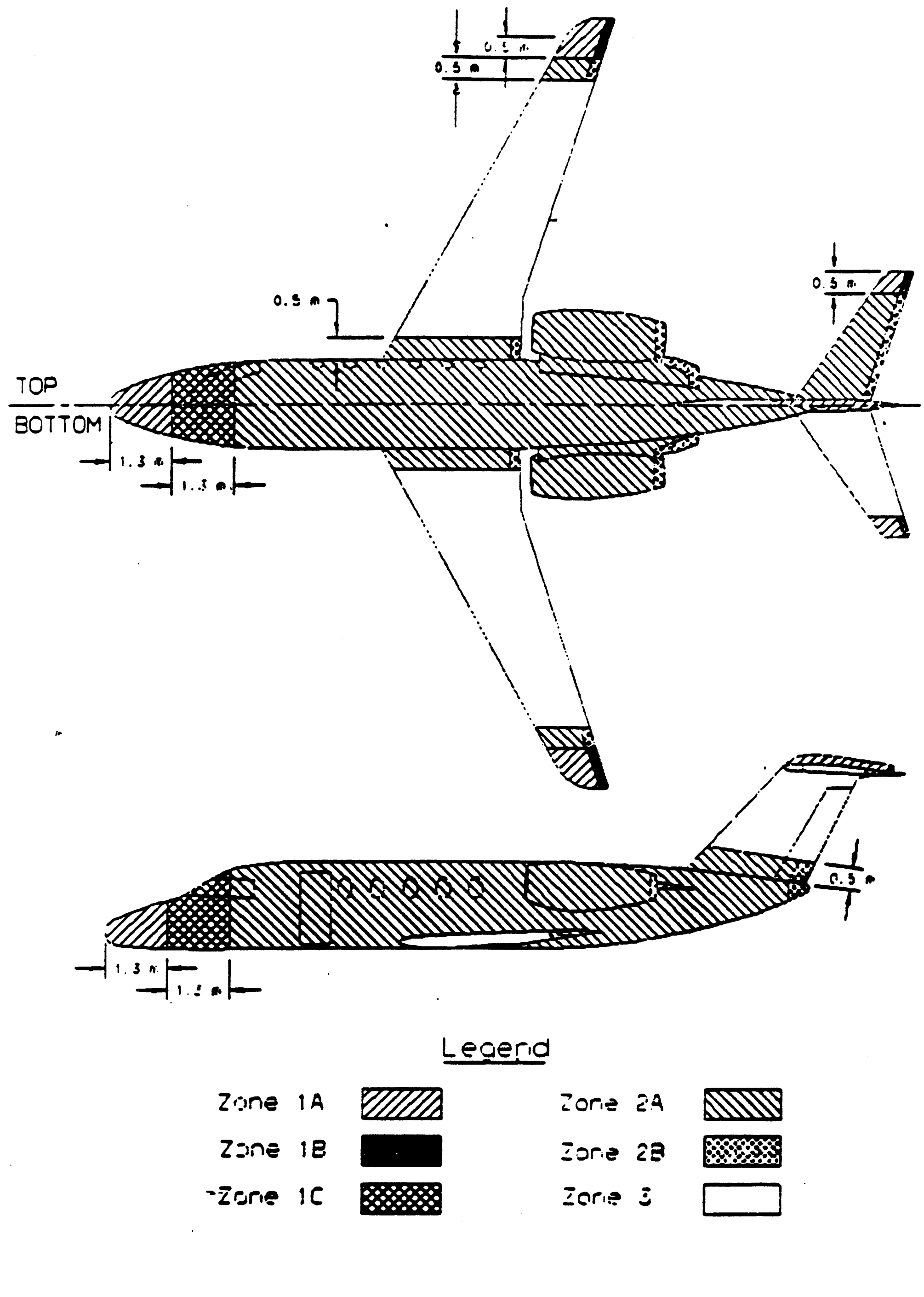


Figure 10-7 - Example of Lightning Strike Zone Details for Swept Wing Business Jet

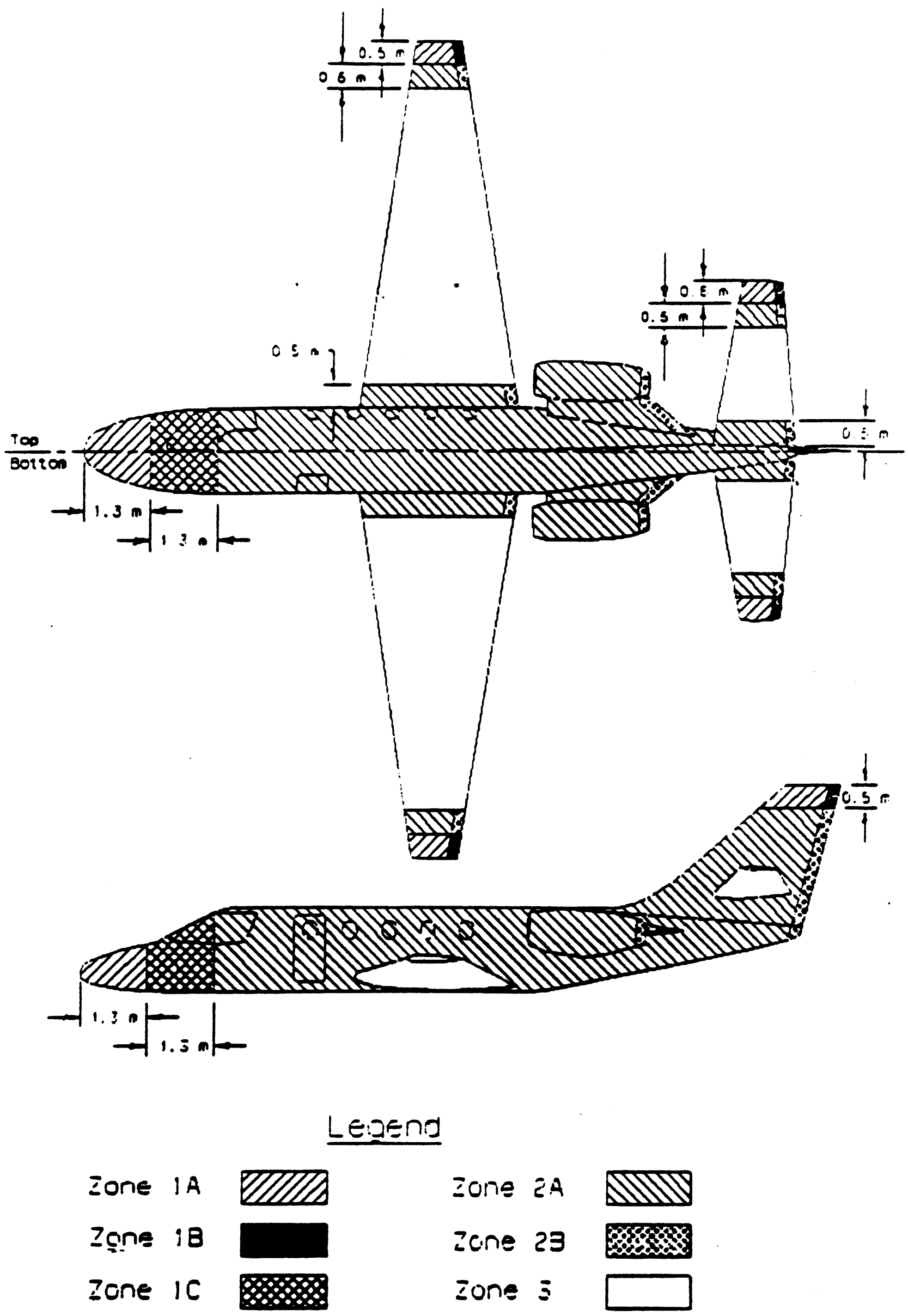


Figure 10-8 - Example of Lightning Strike Zone Details for Straight Wing Business Jet

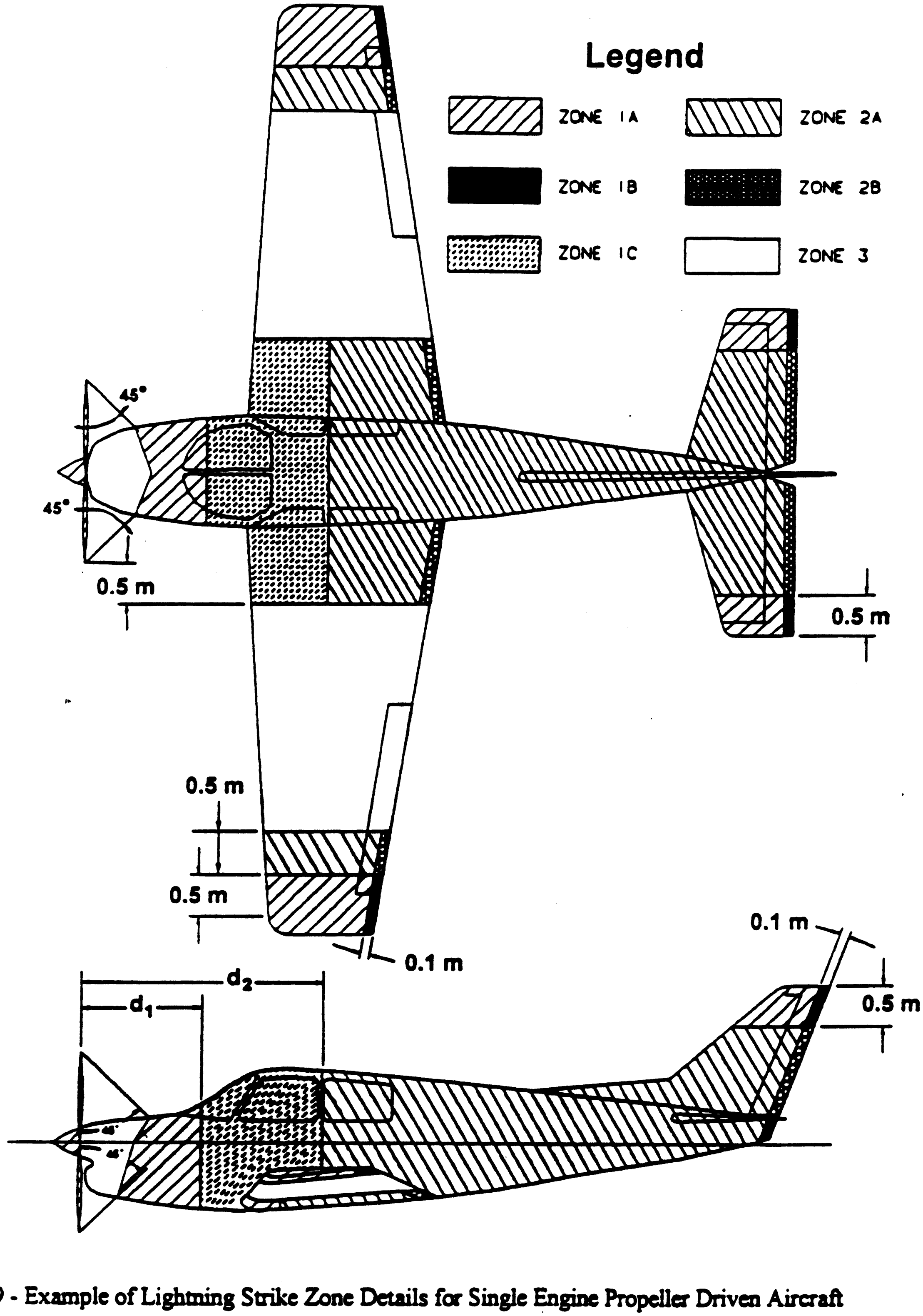


Figure 10-9 - Example of Lightning Strike Zone Details for Single Engine Propeller Driven Aircraft

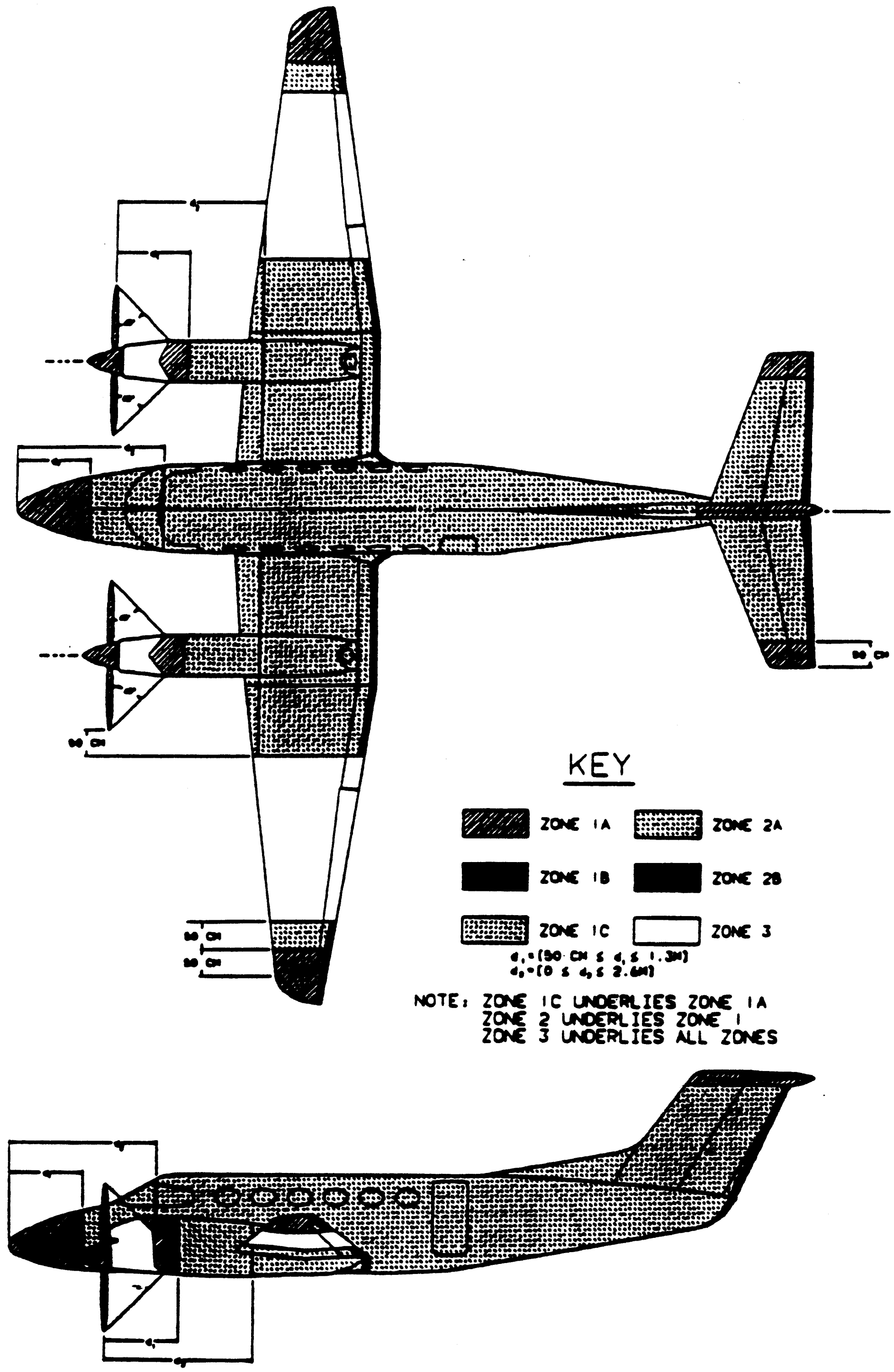


Figure 10-10 - Example of Lightning Strike Zone Details for Multi-Engine Propeller Driven Aircraft

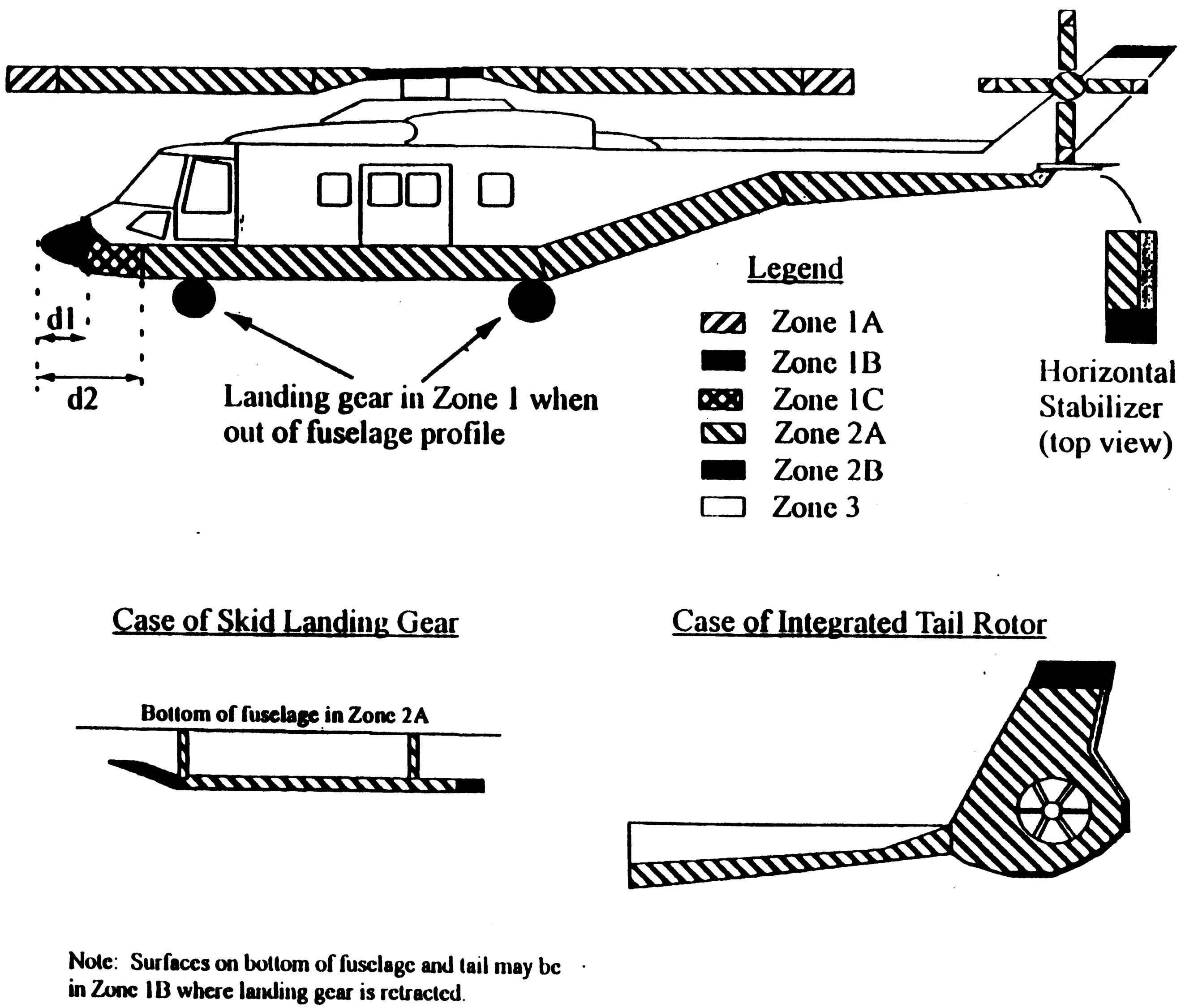


Figure 10-11 - Example of Lightning Strike Zone Details for Rotorcraft

11.0 INITIAL LEADER ATTACHMENT LOCATION METHODS

11.1 Similarity

For new aircraft designs, previous lightning attachment experience on similar aircraft can be used to define the initial leader attachment areas. Similarity basis may include: Scale model test data and/or analysis results for an aircraft (or part of an aircraft) that has been previously certified. Specific features of the new aircraft design and the existing design should be assessed, as described in Section 10.8.

11.2 Service Experience

In flight lightning strike experience to an aircraft of similar geometry to the one whose zones are to be located can be utilized as the basis for establishing the surfaces where initial leader attachment may occur, if sufficient initial leader attachment data is available. The necessary data includes locations of initial leader attachments to existing aircraft. Since leader currents are of low intensity the marks left by them on existing airplanes may be difficult to discern from other lightning attachment marks, or other blemishes. Inspection of aircraft and documentation of strike locations over a period of years can (could) provide sufficient data. Initial leader attachments to frontal surfaces and edges are of greatest interest, since these define the starting region from which leader sweep distances d_1, and d_2 are determined as described in Sections 10.2 and 10.3.

When using service lightning strike experience, care should be taken to distinguish initial leader attachments from marks left by swept flashes and the stroke and continuing currents that flow in these channels, which are indicative of Zones 1A, 1C, and 2A. There will be some overlap, so that stroke and continuing current evidence will also appear in regions susceptible to initial leader attachment. The initial leader attachment for a specific strike will be the forward-most mark. The exception to this is for those trailing edges which are in Zone 1B, where all components of the lightning flash will enter/exit at the same spot.

11.3 Test

11.3.1 Objectives

Initial leader attachment region may be determined by tests of aircraft scale models, or in some cases by tests of full scale parts, where a more detailed assessment of zone boundaries may be desired.

11.3.2 Scale Model Tests

High voltage strike attachment tests to aircraft scale models have been used to determine initial lightning strike attachment locations. The test method has some limitations because of the physics of the simulation, where corona processes, and space charge distributions around the aircraft do not scale linearly with the model dimension. In addition, scale model tests are typically done without a representative net charge on the scale model. Moreover, the effects of airflow and altitude on space charge distributions and local pressure variations are not represented in model tests. Nevertheless, test results from model test arrangements that are possible have compared well with subsequent flight lightning strike experience. The basic procedure is to subject the model to impulsed electric fields in a variety of field orientations to represent possible electric field or oncoming leader orientations. Photographs are taken of the spark attachments to the model, and these indicate the initial leader attachment locations. Instructions for performing model tests are found in Reference 4.2.

11.3.3 Full Scale Tests

Model tests can indicate the regions on the aircraft where initial leader attachments are possible, however, these tests are not adequate to identify detailed attachment possibilities on especially complex geometrical shapes, or on regions which include combinations of electrically conductive and non-conductive surfaces. Should such high voltage strike attachment tests of full scale parts be necessary they must be conducted with representative materials and geometries, to evaluate specific attachment points and breakdown or flashover paths through or across non-conductive surfaces. Instructions for performing high voltage strike attachment tests on full scale parts are given in Reference 4.2.

11.4 Analysis

Initial leader attachment regions may be determined by one or more analytical methods such as electrical field modeling and rolling sphere analysis.

12.0 OTHER ZONING CONSIDERATIONS

12.1 Small Protrusions

Small protrusions produce electric field enhancements over relatively small volumes. These volumes are not usually large enough to initiate a leader discharge from the aircraft. Elements such as antennas, pitot static probes, drain masts, vents, stall fences, nacelle strakes, vortex generators, etc., are typically considered small protrusions provided their height is at least an order of magnitude smaller than the distance between their location and a zone boundary. Small protrusions don't normally affect the general electric field distribution and zoning of the aircraft, but if a small protrusion exists in a Zone 1 or 2 attachment area, it will be one of the more probable attachment points. Aircraft in-flight experience shows that these protrusions are not likely to experience a lightning attachment if they are not already located in Zone 1 or 2 attachment zones.

12.2 Non-conducting Surfaces

Within any of the lightning attachment zones (1A, 1B, 1C, 2A, 2B) there may be surfaces which are not electrically conductive and thus not susceptible to being directly struck by lightning. Initial leader or swept channel attachments may occur to surrounding conductive surfaces, but may, ideally, be swept across non-conductive surfaces to attach to surrounding conductive areas. In some cases, the non-conducting surfaces will have insufficient dielectric strength to prevent lightning from puncturing them, in which case attachment may occur to a conducting object beneath the non-conducting surface. Examples of this situation include a nose radome or a wheel well door fabricated of non-conducting composite material. Such surfaces may not themselves be susceptible to lightning attachment. They should initially, be considered part of the surrounding zone.

13.0 PROTECTION CONSIDERATIONS

In addition to zoning, the consequences of not adequately protecting a given part of the aircraft should be taken into account when determining the appropriate level of protection. It is usually, but not always, more practical to protect the aircraft from the external lightning environment predicted by this zoning standard than to allow the aircraft to suffer the likely damage. However, if it can be clearly demonstrated that there are only minor effects on the aircraft then the level of protection to be provided is discretionary.

Conversely, although areas defined in this standard as Zone 3 have a low probability of direct lightning attachment, components whose failure due to direct lightning attachment would have catastrophic effects, and are located in Zone 3 areas, should be located as far from Zone 1 and Zone 2 boundaries as practicable.

Furthermore, new or novel design features located in Zone 3, which could significantly reduce the level of protection provided by traditional designs, or which have no proven service history, must be shown by test or analysis to withstand a nominal lightning attachment (see reference 4.1) without catastrophic failure. The verification for these design features should be agreed between the applicant and the cognizant certification authority.